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Offshore wind mapping Mediterranean area using SAR

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Abstract

Satellite observations of the ocean surface, for example from Synthetic Aperture Radars (SAR), provide information about the spatial wind variability over large areas. This is of special interest in the Mediterranean Sea, where spatial wind information is only provided by sparse buoys, often with long periods of missing data. Here, we focus on evaluating the use of SAR for offshore wind mapping. Preliminary results from the analysis of SAR-based ocean winds in Mediterranean areas show interesting large scale wind flow features consistent with results from previous studies using numerical models and space borne wind data i.e. scatterometers with lower resolution.

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Keywords: Wind energy; renewable energy; offshore; SAR; Mediterranean.

1. Introduction

In the first phase of planning prospective offshore wind farms, it is of fundamental importance to choose suitable areas worth to be explored in detail. To find such areas, suitable information on the long-term wind characteristics i.e. average wind speed, wind speed and direction frequency distributions and

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spatial variability is needed, especially in the coastal zone where offshore wind has the highest spatial and temporal variability. Standard time series of wind speed and direction are usually available from mast-mounted instruments, such as cup anemometers and wind vanes that provide averages on different time horizons. However, such measurements are local and thus do not provide information on spatial variations in the wind field. Satellite-based wind field maps have the advantage of providing spatial information [1], [2], [3], [4], [5]. Wind mapping based on satellite observations is available from passive microwave, scatterometer, radar altimeter and imaging Synthetic Aperture Radar (SAR) [3]. The spatial and temporal resolution of wind speed based on different satellite-based measurement principles is given in Table 1.

Previous studies [2] and [6], showed the feasibility of wind resource mapping using SAR.

In [6] a series of 1009 ENVISAT ASAR scenes was acquired in Wide Swath Mode (WSM) over the Danish Seas, to verify the applicability of the SAR-based method for wind resource mapping in part of the Baltic Sea. Firstly, SAR-based wind maps were compared to observations from 10 meteorological in situ masts using around 900 collocations. Thereafter, an offshore wind resource map was generated using SAR-based wind maps. Finally, wind resource statistics observed at one site was compared to the SAR-based results, and the wind resource results from existing and planned offshore wind farms were examined. In the present paper we focus on the Mediterranean Sea area characterized by several sub-basins surrounded by complex orography each with characteristic wind regimes generated by the synoptic flow.

The main difference of the wind climatology in Mediterranean area and in the North Sea and Baltic regions consists in the presence of calms, atmospheric stability characteristics and a better developed sea breeze system.

We retrieved SAR images during a ten-year period for a total of 3269 ENVISAT ASAR scenes acquired in Wide Swath Mode (WSM). C-band SAR sensors are normally preferred to other frequency bands when it comes to wind field retrieval. Geophysical model functions, which relate observations of radar backscatter to the 10-m wind speed, the wind direction, and the radar viewing geometry are well established for C-band SAR [7], [8], [9]. C-band SAR sensors have been mounted on several satellite platforms listed in Table 2. SAR images are obtained day and night and in all weather conditions. A SAR is independent of daylight, and additionally, C-band microwave radiation penetrates clouds and precipitation [3]. The final goal of the current study is to estimate the offshore wind resource from a series of satellite wind field maps.

Here, we present preliminary results on the wind characteristics of offshore wind mapping using SAR and show some features of the mean wind field around Calabria, a peninsular Italian region for the whole period, and a case study during 2009.

Table 1. Grid resolution and frequency of satellite-based wind-mapping methods

Remote sensing method	Grid resolution (km ²)	Frequency (GHz)
Passive microwave (i.e. SSM/I)	625-2500	19.35 - 85.5
Scatterometer	150-2500	≈ 5 (C-band) or ≈ 13 (Ku-band)
Radar altimeter	≈ 225	2-3 (E-band) or 26.5-40 (Ka band)
Imaging SAR (C-band)	≈ 2	4-8

Table 2. Satellite platforms with C-band SAR sensors installed and recording periods

Platform	Recording period
ERS-1	1991 to March 10, 2000
ERS-2	1995 to September 5, 2001
Radarsat-1	1995 to present
ENVISAT	2002 to April 8, 2012
Radarsat-02	2007 to April 27, 2008
Sentinel-01	Launch 2013

2. Wind resource mapping from SAR for Mediterranean

2.1. Data set

2.1.1. ENVISAT

We use data from ENVISAT satellite by the European Space Agency (ESA). The domain of investigation is shown in Fig. 1. ENVISAT carried an advanced C-band SAR (ASAR), which may be operated in several different modes with co- or cross-polarization.

The majority of ENVISAT's modes are suitable for ocean wind mapping. In ScanSAR mode, the ASAR sensor is capable of scanning in a 400 km wide swath with a spatial resolution of 100 m.

Table 3 lists the number of scenes per year (a) and per month (b).

Wind speed in the Mediterranean from March 2002 to April 2012 is retrieved using the Johns Hopkins University, Applied Physics Laboratory (JHU/APL) software APL/NOAA SAR Wind Retrieval System (ANSWRS version 2.0) (Monaldo 2000; Monaldo et al. 2006) [2]. The ANSWRS software produces per default high-resolution wind speed fields. The algorithm is initialized using wind directions determined by the Navy Operational Global Atmospheric Prediction System (NOGAPS) models interpolated in time and space to match the satellite data. NOGAPS data are available at 6-hour intervals mapped to a 1°

latitude/longitude grid and the wind vectors from the lowest model level around 10 m above the sea level are used.

To match the satellite data temporal and spatial resolution, the wind vectors are interpolated in time and space. Wind resource mapping using ENVISAT ASAR scenes acquired in Wide Swath Mode (WSM) over the Mediterranean seas has been performed. The statistical analysis of SAR wind map is performed with the Satellite –Wind Atlas Analysis and Application Program (S-WAsP) tool developed by DTU Wind Energy. S-WAsP is a software for wind resource estimation based on input of SAR wind maps from ANSWRS [2].

A total of 3269 scenes were included in this study. Fig. 1 shows the number of overlapping samples. Most samples cover the northern part of the Adriatic Sea, the Ligurian Sea and the Sea of Sardinia.

2.1.2. Coastal area measurements

As in Mediterranean there are limited offshore experimental data, to evaluate our results, it would be possible to compare wind climatologies obtained from SAR images, with observed wind data collected at buoys, islands and coastal data located in different Mediterranean regions.

We present a study on the area around the Italian Calabria region, a long and narrow and mountainous peninsula in South Italy that causes significant wind conditions variability from one coast to the other.

We use here hourly wind data from a 10 m mast measuring hourly wind speed and direction located at the coastline at the harbour of the town of Crotona, belonging to the marine network of sensor of ISPRA (Institute for Environmental Protection and Research). The dataset is for the period from 1 January 2006 to 31 December 2010.

2.2. Preliminary results: wind maps

Fig. 2 presents an example of how high resolution SAR images allow seeing patterns in the wind field induced by the orography. We note the high wind speed (in yellow) in correspondence of the only valley that connects the Tyrrhenian Sea to the Ionian Sea. The pattern might represent both the channelling created either by sea breeze or by the synoptic flow.

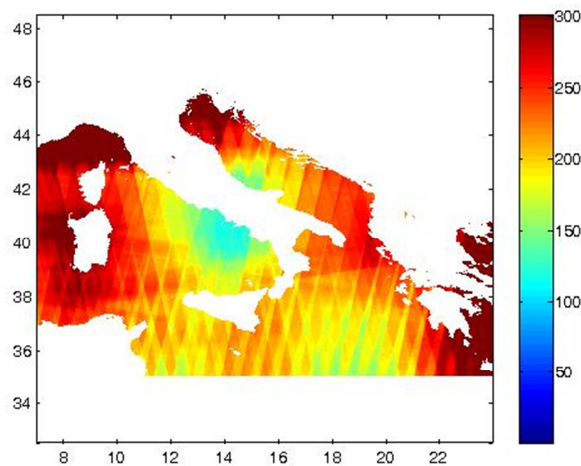


Fig. 1. Number of overlapping ENVISAT ASAR WSM images that are available for the Mediterranean seas

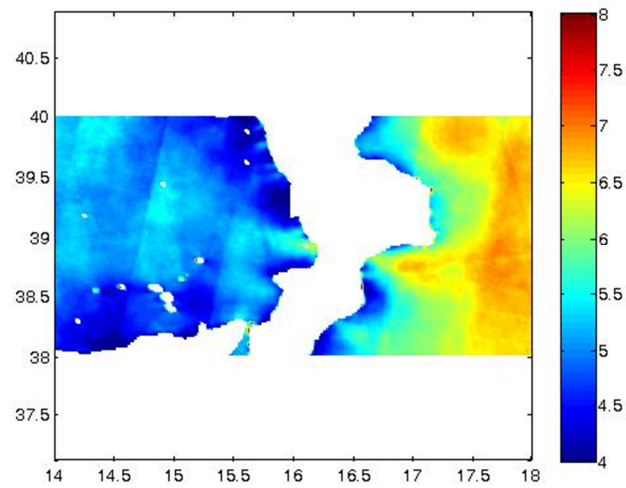


Fig. 2. Mean wind speed (m s^{-1}) estimated from a total of 3269 ENVISAT ASAR WSM satellite images covering the sea around Calabria

Table 3. ENVISAT ASAR data used in the study per year (a) and per month (b)

Year	Number of scenes	Month	Number of scenes
2002-2004	8	January	294
2005	203	February	261
2006	154	March	281
2007	448	April	298
2008	814	May	269
2009	606	June	143
2010	449	July	246
2011	450	August	278
2012	137	September	319
		October	280
		November	269
		December	331

2.3. Preliminary results: – a case study

As a case study, we focus again on the Calabria region, where breezes play a major role for the local climate causing wind conditions variability at the opposite sides of peninsula.

For the purpose of studying the suitability of wind directions from the NOGAPS model, used to initiate the SAR wind speed retrieval, in studying coastal areas, we present results from year 2009 covering the area using a subset of 44 satellite images from ENVISAT ASAR. There are 36 morning passes observed between 8.50 and 9.16 UTC, and 8 images between 20.45 and 20.54 UTC.

Due the lack of offshore dataset for the area, the only way to test the consistency of the wind climatology from SAR is to take into consideration the coastal site of Crotona.

Furthermore, we also analysed the correlation of NOGAPS wind direction on either side of the peninsula

We selected three points of the SAR images at distances of 4.5, 50 and 200 km of the two opposite sides of peninsulas (Fig. 3).

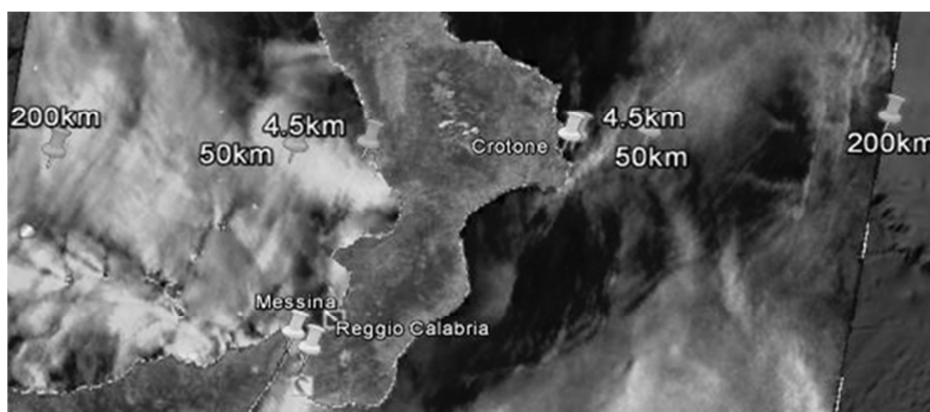


Fig. 3. Points chosen for the comparative analysis of the case study of Crotona 2009

Concerning the wind speed, statistical analysis using the subset for whole 2009 shows that the correlation coefficient R^2 between selected sites within the SAR images and NOGAPS model varies from $R^2=0.7$ to $R^2=0.8$ from 4.5 km to 50 km offshore respectively. This means that the SAR is better describing the wind variation caused by the coastal influence.

When considering the correlation coefficient R^2 between wind speed at the SAR locations and the mast, R^2 varies from 0.4 to 0.6. The low correlation between SAR and mast at 4.5 km from the coast might be ascribed to different factors i.e. the ship tracks outside the harbour of Crotona or the incorrect wind direction from NOGAPS around the peninsula.

Regarding the NOGAPS wind directions, Fig. 4 (a) illustrates that the correlation coefficient of NOGAPS wind directions from 4.5 to 50 km is $R^2=0.99$. This high correlation could be attributed to the fact the two points are located in the same NOGAPS grid cell.

Another example is on the NOGAPS wind direction difference at either side of the Calabria region at two points chosen 4,5 km offshore. The coefficient of correlation between NOGAPS data wind direction of two opposite sides of peninsulas, is $R^2=0.85$. The high correlation confirms the limit of the NOGAPS

horizontal resolution in presence of peninsulas. Therefore, in such cases, models with higher spatial resolution would probably be more appropriated and future work will address this issue.

In Fig. 4 and Fig. 5 the few observations near 0° and 360° are removed before the correlation analysis [6].

Since in Mediterranean area there are limited offshore experimental data, we have performed a qualitative analysis of satellite observation comparing SAR with the available experimental data from the coastal mast of Crotona, located on a promontory (Fig. 3). The comparison of the wind distribution in Fig. 6 shows that the SAR wind distribution reproduce the shape of the coastal orography; the difference between the mast and SAR is that the mast might catch wind flow features induced by the land i.e. the flow field adapting to the coastal shape. In Table 4 it is observed that SAR tends to overestimate the mean wind speed. The presence of calm is likely one of the issues of the differences, because SAR wind speed threshold is 2 m s^{-1} .

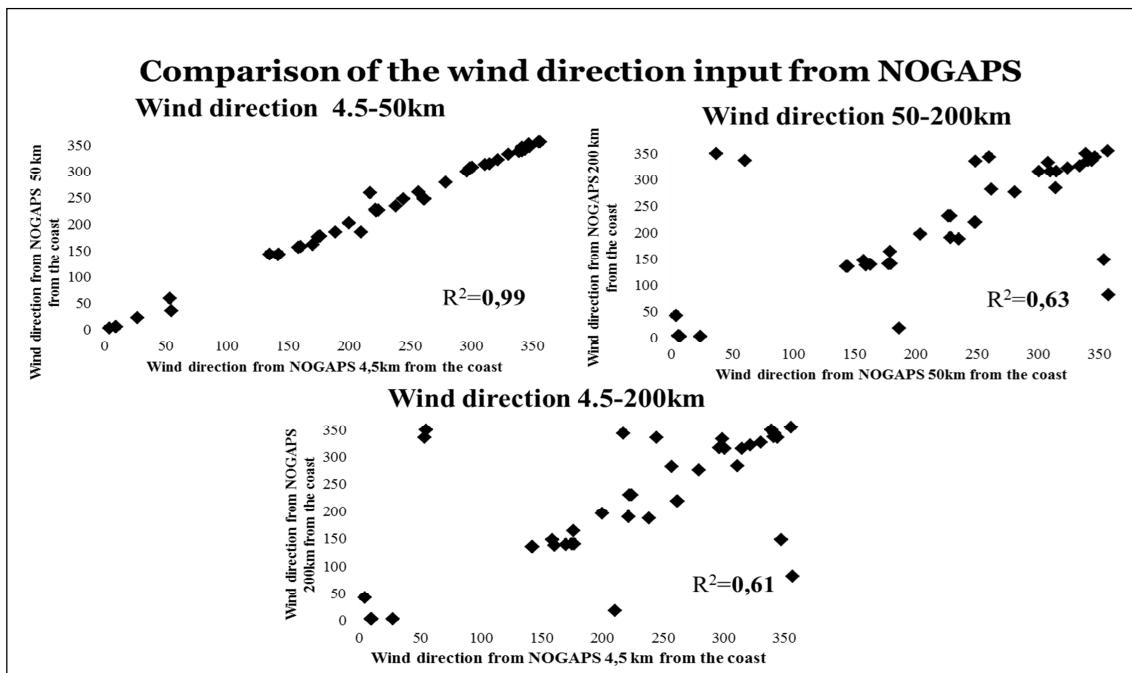


Fig. 4. Case study of Crotona 2009 - Comparison of the wind direction input from NOGAPS at 4.5-50 km offshore (a), 50-200 km (b) offshore, and 4.5-200 km offshore (c)

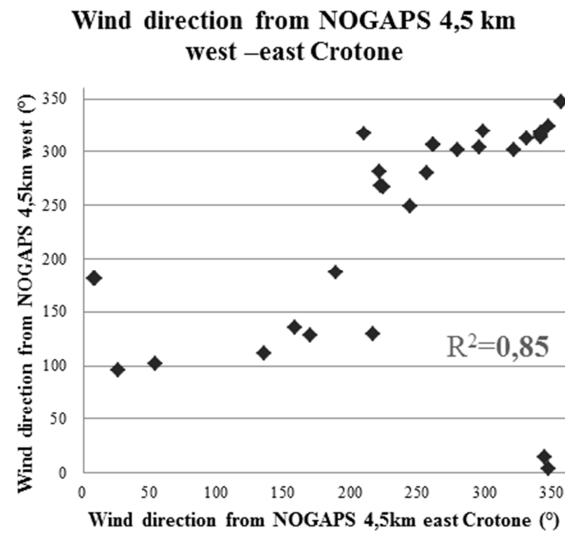


Fig. 5. Case study of Crotona 2009 - Comparison of the wind direction input from NOGAPS at either side of the peninsula

Table 4. Case study of Crotona - Comparison of mean wind speed U and Weibull coefficient A and k between meteorological mast (2006-2010) and SAR (2002-2012)

Parameters	Mast	SAR
U (m s^{-1})	4.5	5.49
A (m s^{-1})	4.9	6.1
k	1.37	1.69

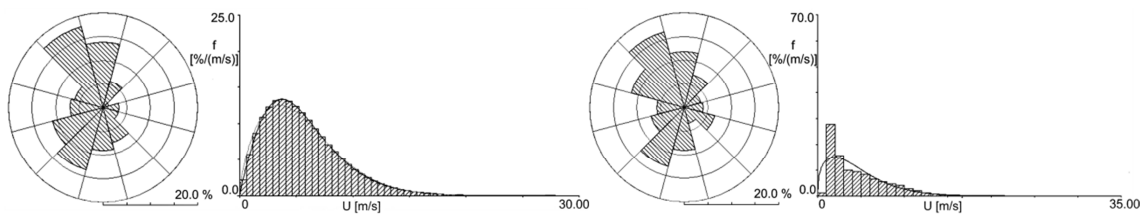


Fig. 6. Case study of Crotona - SAR (2002-2012) (a) and Experimental data (2006-2010) (b) wind distributions. The maximum frequency in the wind rose is 20% for SAR and for Experimental data

4. Conclusions

We presented preliminary results from the analysis of SAR-based ocean winds in Mediterranean area. Since SAR images allow wind retrieval at high resolution, they are suitable for estimating the coastal wind climatology.

Here, we showed the wind climatology for the Mediterranean obtained using wind data retrieved for the whole ENVISAT mission. The resulting wind maps show reliable flow patterns induced by the orography i.e. flow channelling.

For a case study, we used a subset of 44 SAR images during 2009, where we compared SAR wind to wind observations from a coastal meteorological mast located in the Italian Calabria Region, a long and narrow peninsula in the middle of the Mediterranean.

This new technique is seen as a supplement to classical wind sampling and modelling efforts, not as a stand-alone alternative. The SAR methodology is certainly useful as a guide to positioning an offshore meteorological mast for detailed wind resource estimation.

Since SAR images cover most of the globe, a global model is needed to provide wind directions for ready wind speed retrieval algorithms. The NOGAPS model with its 200 km horizontal spatial resolution is used to fulfil this purpose.

The ANSWRS retrieval software produce high-resolution (<1 km) wind speed fields initialized used wind direction determined by NOGAPS. However, this method might be the best operational solution over the open ocean but in presence of peninsulas less than 200 km wide/long i.e. Calabria, inducing different wind climatologies at either sides i.e. sea breezes, this methodology might not be the best one.

Work is in progress to study the accuracy of the ANSWRS 2.0 - SAR wind retrieval system, using as input the RAMS mesoscale model at 10 km resolution.

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